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X-ray observations of Nova Muscae by means of the *Watch* instrument

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A new bright transient x-ray source was discovered 8 January 1991 by the *Watch* instrument aboard the *Granat* observatory. The maximum flux from this newly discovered source was 2 Crab units in the 8–20 keV spectral band. From 16 to 21 January the *Watch* instrument detected a dip in the light curve of the x-ray nova. On 16 January 1991 the flux dropped to 0.5 Crab units. After five days the source again became brighter. Light curves in two energy bands are presented.

Discovery. A new bright x-ray source was first discovered from the data gathered by the *Watch* instrument aboard the *Granat* observatory and received on earth on 9 January 1991 (Lund and Brandt, 1991). It was also detected in the standard x-ray band by an all-sky instrument aboard the Ginga satellite (Makino, 1991). It appeared in the field of view of one of the *Watch* 1 instrument's detectors at the start of the instrument's observations following the satellite's departure from the earth's magnetosphere, which corresponds to January 8.5 UT. The new object was far brighter than the well-known x-ray sources Vela X-1 and GX 301–2, which were simultaneously observed in the same field. The daily mean flux amounted to approximately 1.4 Crab units. Because the new source was so bright, it was possible to localize it quite precisely, with an uncertainty in the coordinates of around 20', which is, in theory, the limit of the *Watch* instrument's precision. The following coordinates were obtained for epoch 1950.0: $\alpha = 11^{\text{h}}23^{\text{m}}$, $\delta = -68^{\circ}1'$. The localization carried out several days later, using both coded aperture x-ray telescopes and visual identification (West, 1991), made it possible to determine the coordinates of the new source to high precision (epoch 1950.0): $\alpha = 11^{\text{h}}24^{\text{m}}10^{\text{s}}$, $\delta = -68^{\circ}24'$ (Syunyaev et al., 1991), a result that differs by only several arcmin from the center position found by the *Watch* instrument. The new source was named Nova Muscae (GRS 1124–683).

The data received on earth on 9 January 1991 had been stored in the onboard storage unit of the *Watch* instrument for around 24 h, beginning 8 January. From an analysis of the light curve of Nova Muscae during this time it was possible to determine the time it had been first detected by the *Watch* instrument to be 8 January 1991 (8.5 UT). During this time the flux from the object amounted to 900 mCrab and increased to 1.9 Crab by January 9.6 UT (Fig. 1). Hence, it may be concluded that the outburst of Nova Muscae had most likely begun during the first 12 hours of 8 January 8. Unfortunately, the *Watch* instrument could not perform any observations during this period of time because the *Granat* observatory was then crossing the earth's magnetosphere and, consequently, was experiencing extremely poor background conditions. On 5 January, the source was not bright enough to be detected by the *Watch* instrument. An analysis of the data for that day showed that the source had a brightness of at most 70 mCrab.

Light curves. The rapid growth and high level of the x-ray flux from Nova Muscae led to virtually continuous observations of the object by the *Watch* instrument. January 1991 proved to be a good month for carrying out observation of the region in the sky containing the nova using the *Watch* instrument. Because of the limited pointing capabilities of the *Granat* observatory, the source was observed mainly through the *Watch* instrument's first detector, which was the best of the four detectors. Only the regular (once every four days) periods when *Granat* crossed the earth's radiation belts interfered with continuous observations of the light curve, and the instrument was turned off during these times. From Fig. 2 it is possible to judge the degree of stability of the observing conditions for Nova Muscae during January and February 1991. The figure also shows the background count rate in the *Watch* instrument's first detector. It is characterized by a very slow variation throughout the period 8 to 26 January. This would appear to indicate that the light curve of any bright source established in this detector may, in theory, be established with nearly the same relative error of several percent (which is much less than the statistical error). On 26 January 1991, all of the *Watch* instrument's detectors recorded a rapid increase in the background count rate, which led to a temporary shutdown of the instruments. The instrument interpreted this increase in background as indicating that all three detectors were entering the earth's magnetosphere. Since all three detectors recorded this phenomenon at the same time, it would appear to be due to external factors, most likely a bright solar flare. The instruments were not able to function again until early in February 1991. In only two runs during that month, however, was it possible to determine the flux from the nova reliably. Because of the type of pointing chosen for the *Granat* observatory, in all other runs there were other bright x-ray sources in the field of view besides Nova Muscae. Because of the presence of these sources, together with the incident flux from Nova Muscae, the errors in reconstructing the signal from the nova proved to be significantly greater than the absolute value.

Figure 3 depicts the light curve of the Nova Muscae x-ray source from data gathered by the first of the *Watch* instrument's detectors in the 8–20 keV energy band. The light curve is characterized by a rapid increase in the flux on 8–9 January from 0.9 to 1.9 Crab. Each point on the curve was obtained by integrating approximately four hours of observa-

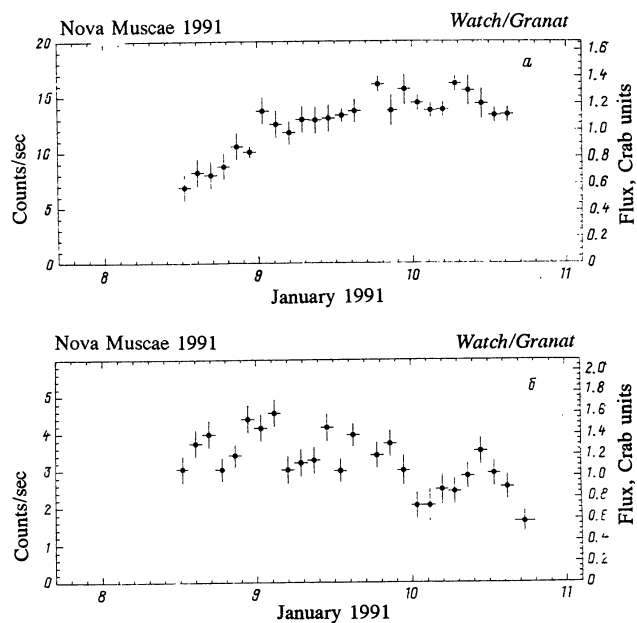


FIG. 1. Light curves of the x-ray source Nova Muscae during the first two days of observation. (a) 8-20 keV band; (b) 20-60 keV band.

tion. Note that variations in the brightness of a source lasting several hours are statistically significant (compare Fig. 1, where 3σ excursions at UT 9.0, 9.77, and 10.28 are clearly visible). Figure 3 also presents data from the ART-P telescope (Grebenev et al., 1992).

Figure 4 presents the spectrum hardness, that is, the ratio of the flux in the 20-60 keV band to that in the 8-20 keV band. The figure supplies a graphic demonstration that, based on the data gathered by the *Watch* instrument, the hardness of the source is decreasing over time, and that it was at a maximum at the time the object was discovered. Note that the soft component in the standard x-ray band attained a maximum only on the fifth day after the *Watch* instrument had discovered the object.

Figure 5 presents the two-color diagram for the Nova Muscae x-ray source based on data gathered the first two days of observations after the discovery. The diagram also demonstrates that at the time of maximum light, the spectrum of the source was typified by minimal hardness. Conversely, the flux minimum corresponds to maximum spectrum hardness.

Decrease in brightness from 16 to 21 January. The marked drop in the count rate between 16 and 21 January

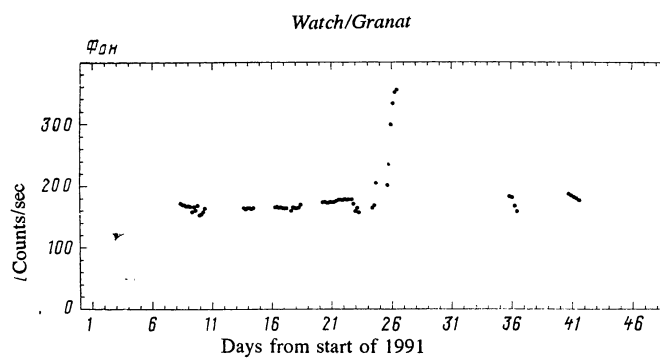


FIG. 2. Background count rate in the *Watch* instrument's first detector during January-February 1991 in the 8-20 keV band.

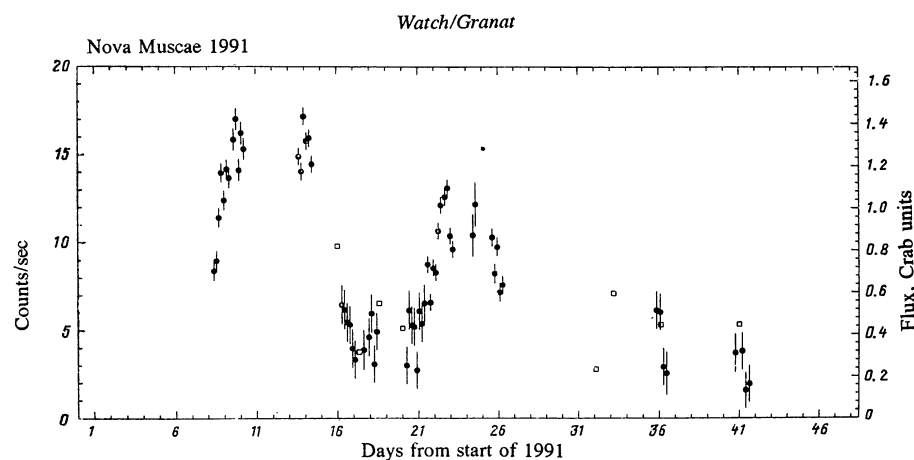


FIG. 3. Light curve of Nova Muscae in the 8-20 keV band January-February 1991. Points for 16-20 January and for 5 and 20 February have been adjusted (cf. text). The small squares represent data gathered by the ART-P telescope in the 8-20 keV band (Grebenev et al., 1992).

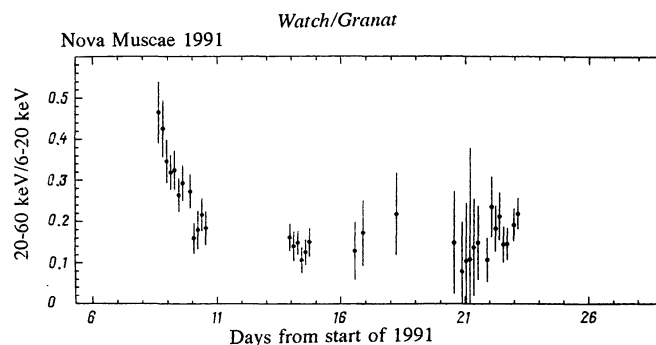


FIG. 4. Time dependence of spectrum hardness for Nova Muscae.

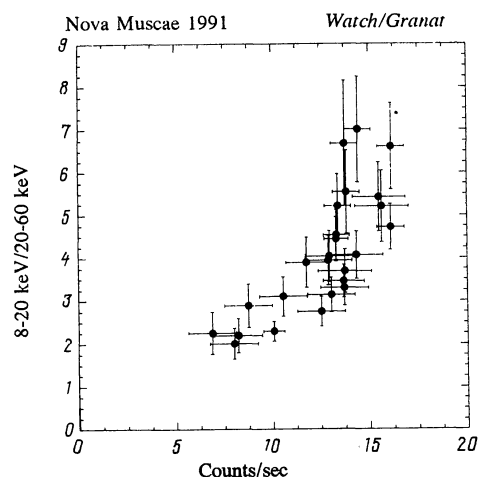


FIG. 5. Two-color diagram of Nova Muscae obtained 8-10 January 1991.

1991 is the most interesting feature on the light curve (Syun'yaev, 1991). Unfortunately, that was exactly when the *Granat* observatory was pointed at Nova Muscae following its discovery by the *Watch* instrument. It is important to bear in mind that when the *Granat* observatory was similarly pointed at the Crab nebula, the *Watch* instrument recorded only half its flux. It is our belief that some element of the SIGMA telescope occulted the observed source for the first detector.

This element must have been rather thin, since it did not affect the observations in the 20-60 keV band. Figure 6 presents the light curve of the nova in the 20-60 keV band. There are also points shown in that figure that were obtained by the SIGMA telescope in the 35-60 keV band (Gil'fanov et al., 1991) normalized with respect to the flux from the Crab nebula.

We corrected the light curves of the nova for 16-21 January 1991 under the assumption that the slope of the nova's spectrum in the 8-20 keV band is equal to the slope of the spectrum of the Crab nebula, if the values we obtained are multiplied by a factor of 2 (a figure that was obtained from observations of the Crab nebula by the first of the *Watch* instrument's detectors at different angles). Note that on the basis of the data gathered by the ART-P telescope, the slope of the nova's spectrum differed from that of the Crab nebula by 10% (Grebenev et al., 1992). There was still a dip in the light curve. It is most likely that the dip was genuine, and not an instrumental effect. A rough quantitative estimate of the nova's flux in the dip yields a value in the range 0.4-0.5 Crab unit in the 8-20 keV band. This value is in agreement with data in the 20-60 keV band, as well as with data gathered by the SIGMA and ART-P telescope.

Discussion. The x-ray source Nova Muscae is one of five bright x-ray novae that have been investigated in detail over the past 20 years together with the x-ray sources Nova Monocerotis (1975), Nova Ophiuchi (1977), Nova Vulpeculae

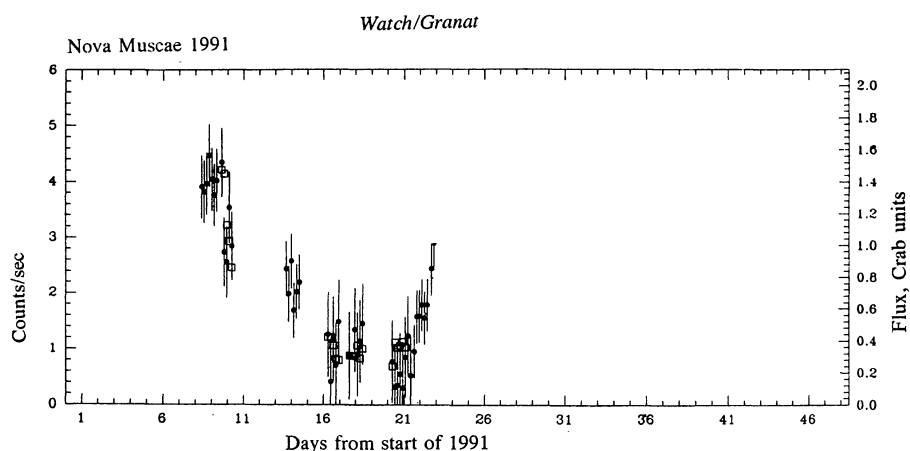


FIG. 6. Light curve of Nova Muscae in the 20-60 keV band in January 1991. The small circles represent the data from the first of the *Watch* instrument's detectors; the small squares, the data from the SIGMA telescope expressed in Crab flux units.

(1988), and Nova Cygni (1989). X-ray novae are of particular interest inasmuch as the system A 0620 – 00 (Nova Monocerotis) is, according to dynamic evidence, among the leading black hole candidates (McClintock and Remillard, 1986). The discovery of Nova Muscae by the *Watch* instrument made it possible to localize and discover a star that varied in brightness from 21^m to $13^m.5$ (West, 1991). One of the most important results obtained by the *Watch* instrument was the discovery of a dip in the light curve, which proved that this light curve differed from the light curve's with exponential drop and characteristic period of around 30 days typical of Nova Monocerotis, Nova Cygni, and Nova Vulpeculae (Tanaka et al., 1991). Thus, the detection of this dip is the first evidence of the fact that the hard tail in x-ray novae has a different time-dependency than the soft component, which yields the principal contribution to the luminosity of the source.

It is doubtful that the dip observed from 16 to 21 January could be associated with an eclipse of the source by a gaseous flow. First of all, this dip was not detected in the standard x-ray band by the Ginga satellite, but instead appeared only within the range of sensitivity of the *Watch* instrument, that is, at energies exceeding 8 keV. Thus, if an eclipse of the extended object did take place, only the zone corresponding to radiation in the hard range would have been covered. It is more likely that the dip was due to the disappearance of factors that produce the hard component in the spectrum. It could have involved, for example, attenuation in flare (coronal) activity on the surface of an optically dense

disk. The appearance of a dip is difficult to connect with the variation in the luminosity of the object or, what is the same thing, the rate of accretion, since at the end of January 1991 more than 90% of the luminosity of the object was due to the soft component, that component decreased exponentially with characteristic period of 30 days.

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